Thermal Analysis of Next Generation Space Telescope (NGST) Mirrors During Optical Testing in the X-Ray Calibration Facility (XRCF)

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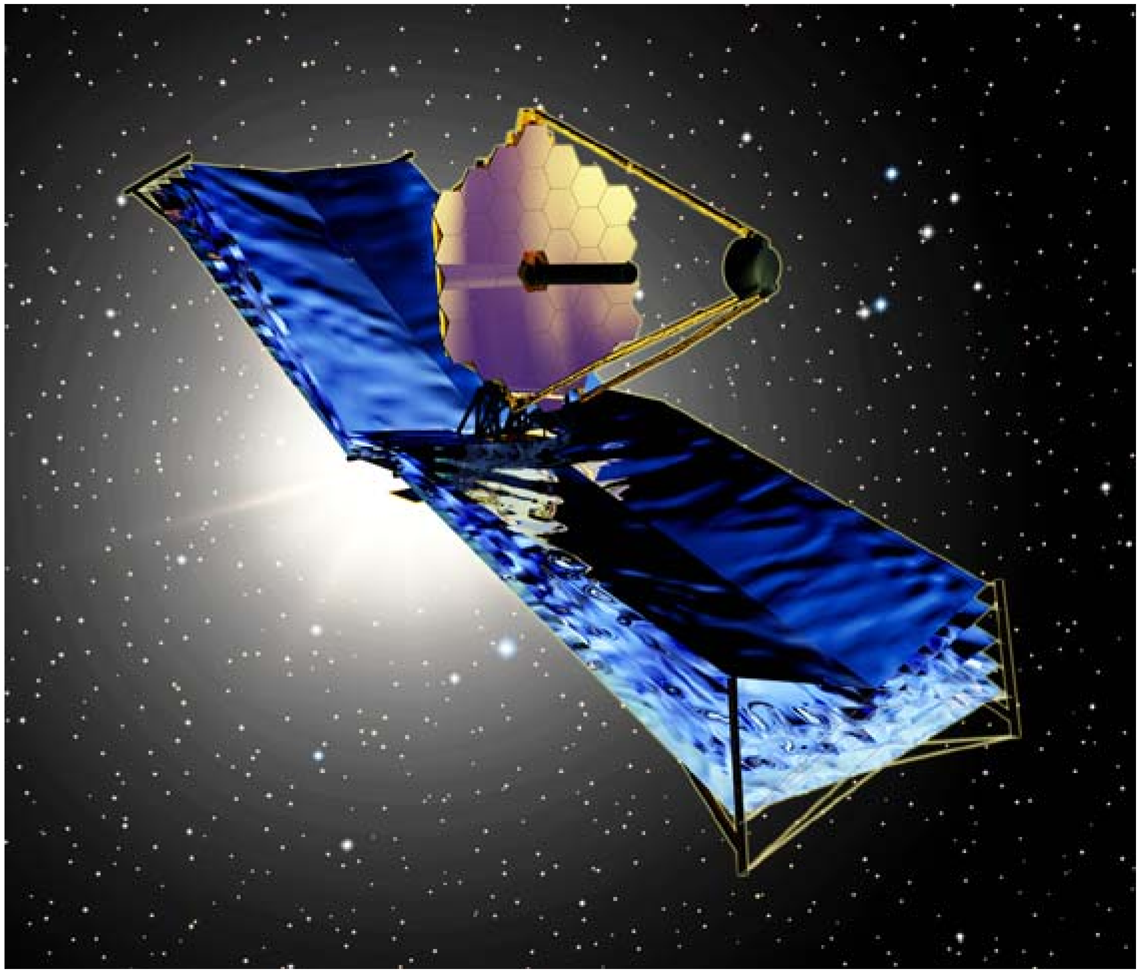
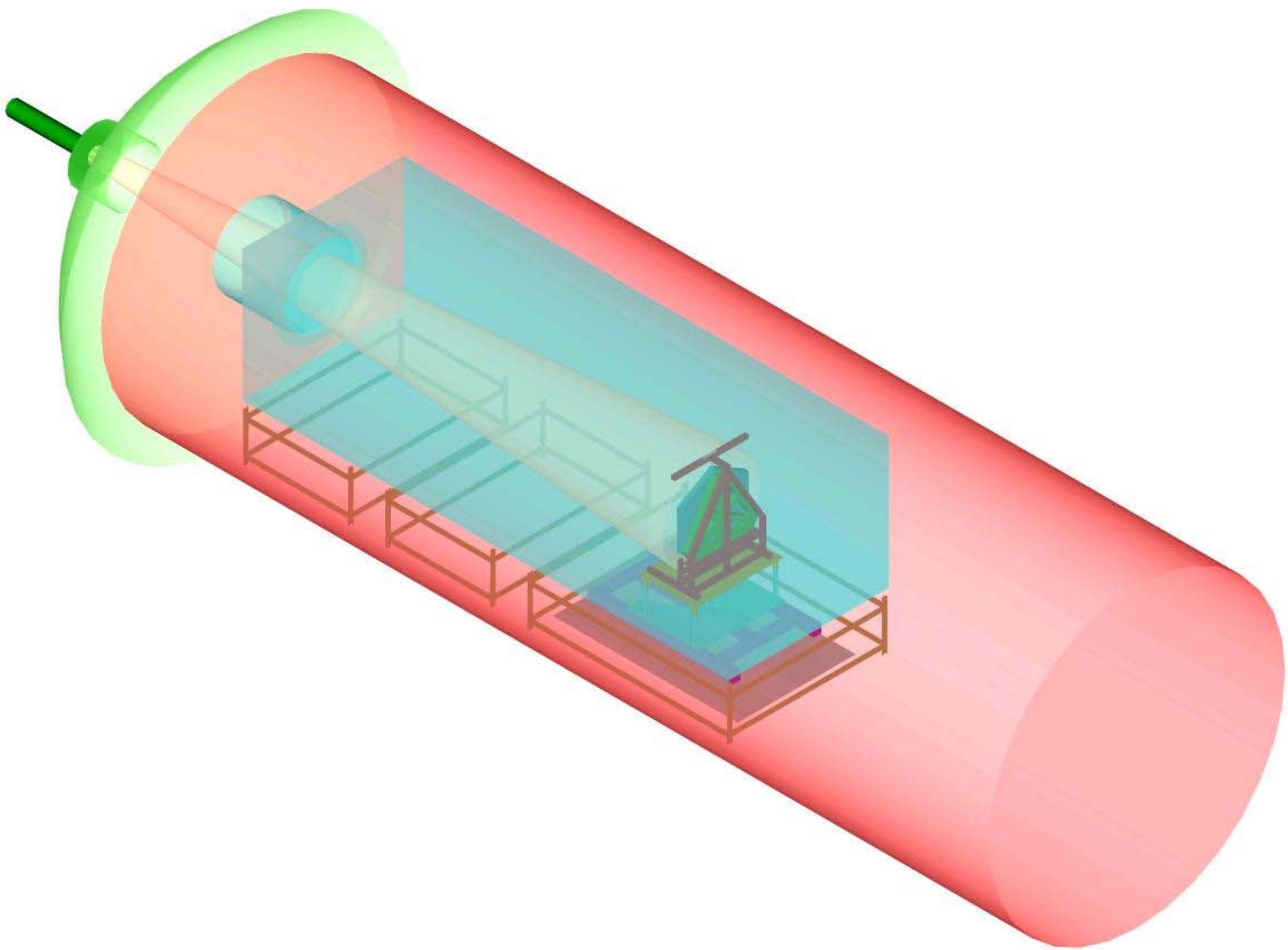
NGST Spacecraft Concept



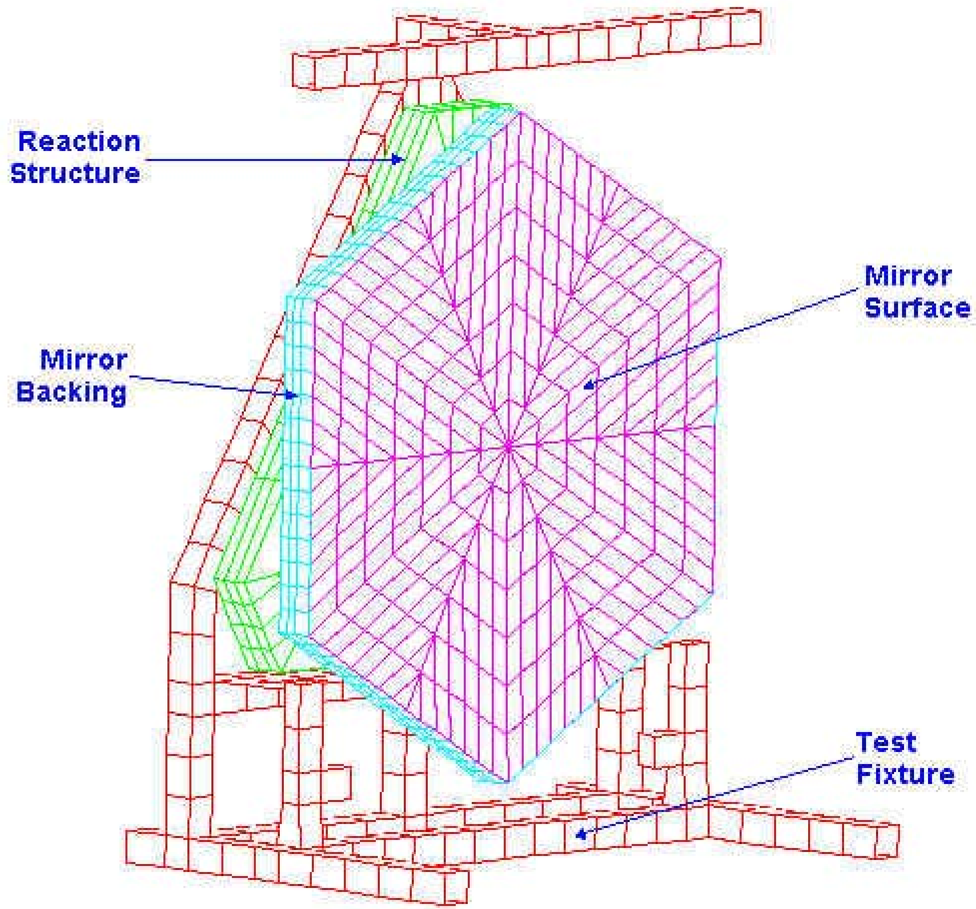
NGST Mirror Development Testing

- The NGST program and industry partners are developing extremely light-weight mirror designs.
- NGST development mirrors are being tested at MSFC.
- Target temperature for development mirror testing is 35 K.
- Conduction and radiation are not sufficient to conduct thermal vacuum testing in a reasonable time.
- Helium gas is injected into the vacuum chamber to accelerate temperature transitions during testing.
- Free-molecular conduction can be modeled by adapting present thermal analysis techniques.

NGST Mirror in the XRCF



NGST Test Article



NGST Development Mirror

Knudsen Number

Knudsen Number	$\mathrm{Kn} = \lambda / L_e$	Ratio of Mean Free Path to Characteristic Dimension
Mean Free Path	$\lambda = \dfrac{\mu}{p}\sqrt{\dfrac{\pi R_u T}{2 g_c M}}$	μ = Gas Viscosity p = Gas Absolute Pressure R_u = Universal Gas Constant T = Gas Absolute Temperature M = Gas Molecular Weight
Characteristic Dimension	$L_e = 4V/A_w$	V = Enclosure Volume A_w = Enclosure Surface Area

Heat transfer and flow regimes are defined in terms of the Knudsen number.

Continuum	$\mathrm{Kn} < 0.01$
Mixed	$0.01 < \mathrm{Kn} < 0.30$
Free-molecular	$\mathrm{Kn} > 0.30$

Free-Molecular Conduction

The radiation heat transfer between two gray surfaces may be represented by:

$$Q = \sigma F_e F_{12} A_1 (T_2^4 - T_1^4).$$

Similarly, the free-molecular conduction between the two surfaces may be represented by:

$Q = G\, p\, F_a F_{12} A_1 (T_2 - T_1)$, in which

$$G = \frac{\gamma + 1}{\gamma - 1}\sqrt{\frac{g_c R_u}{8\pi MT}}$$

p = Gas Absolute Pressure and

F_a = Accommodation Coefficient Factor.

R_u = Universal Gas Constant
M = Gas Molecular Weight
T = Pressure Gauge Absolute Temperature

Accommodation Coefficient

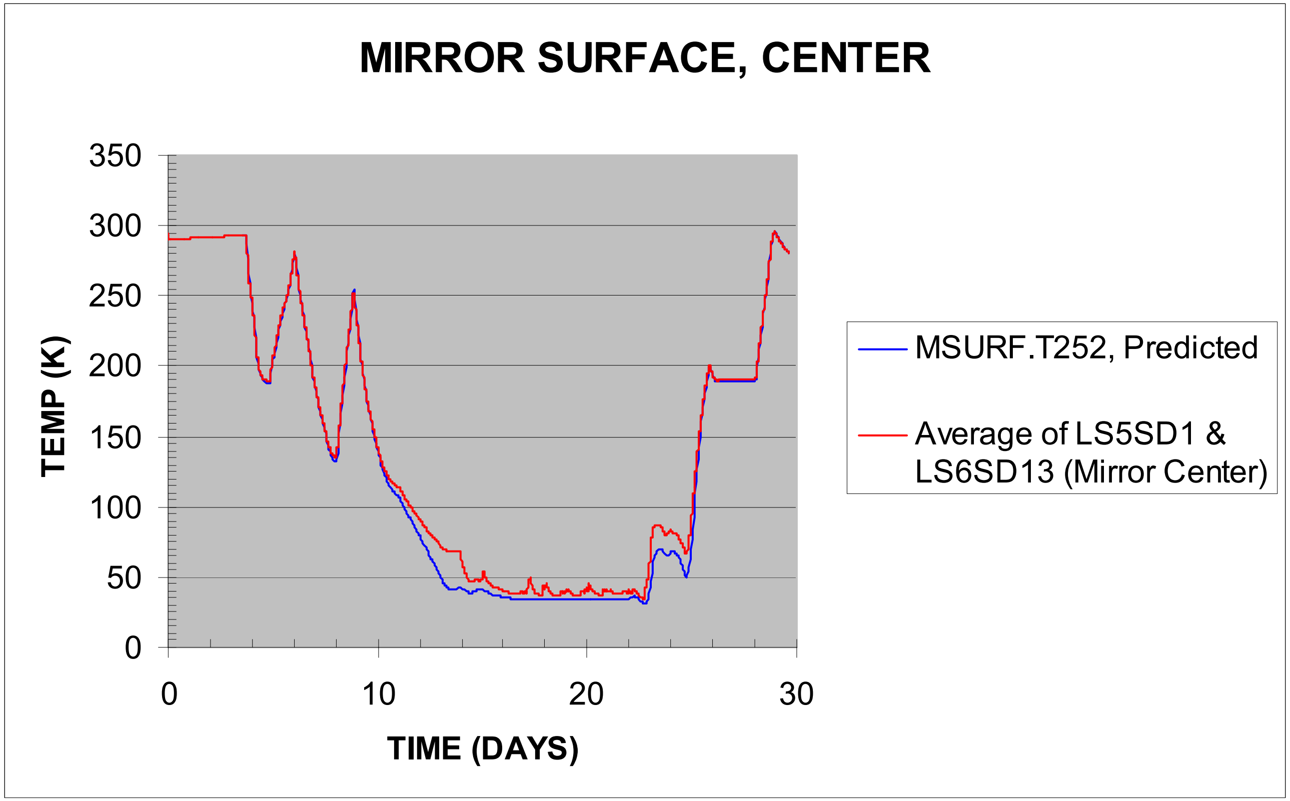
The Accommodation Coefficient, **a**, is analogous to the Emissivity, ε, and its value depends on the specific gas/surface combination and the surface temperature. It represents the degree of approach of the gas molecules to thermal equilibrium with the bounding surfaces.

Accommodation Coefficients for Gases of Interest

Temp. (K)	**He**	**Air**	**Ne**	**H_2**
20	0.59	1.00	1.00	0.97
78	0.42	1.00	0.83	0.53
300	0.29	0.8-0.9	0.66	0.29

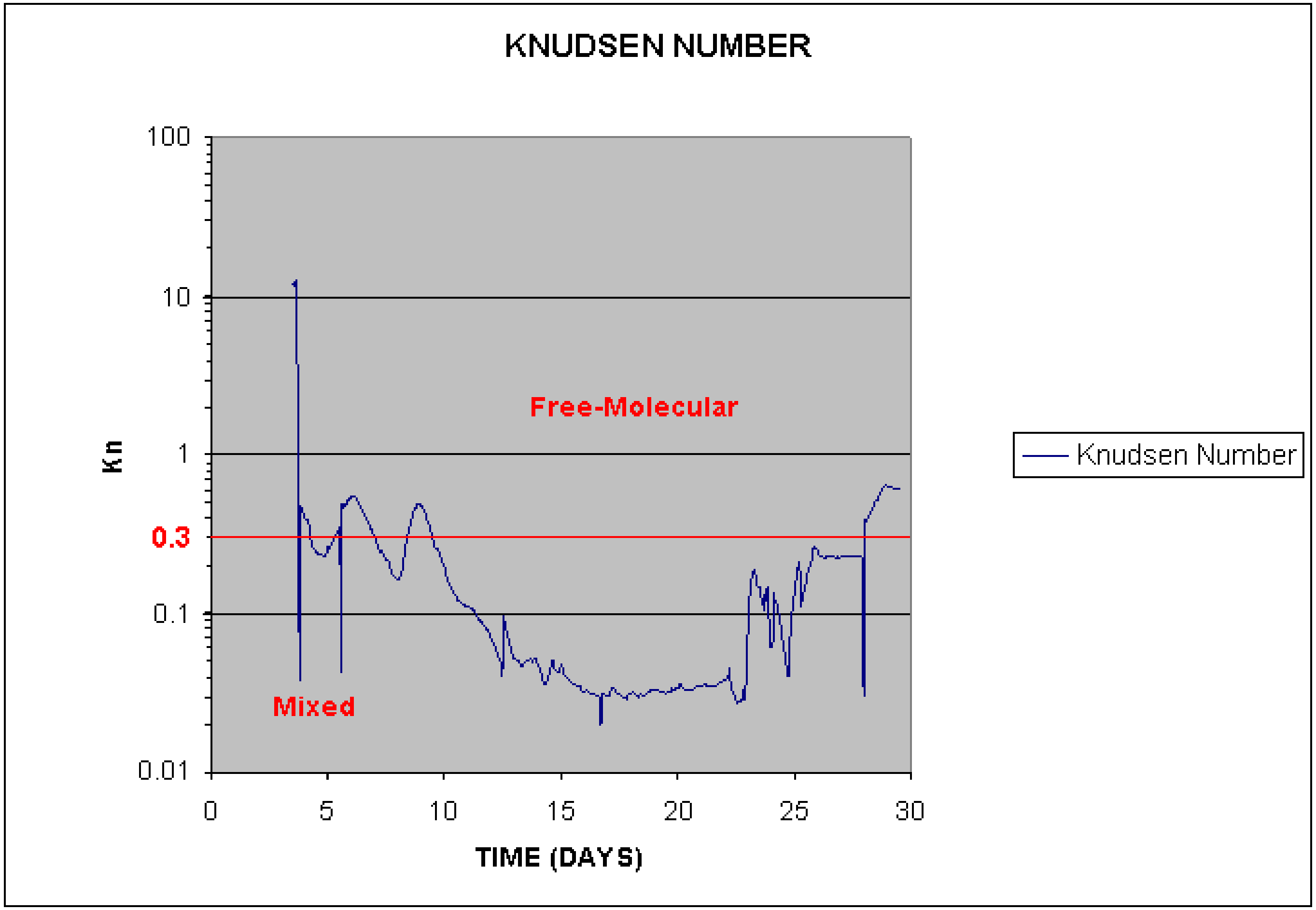
F_a , the Accommodation Coefficient Factor, is analogous to the Emissivity Factor, F_e. All expressions for F_e may be applied directly by substituting **a** for ε.

Results



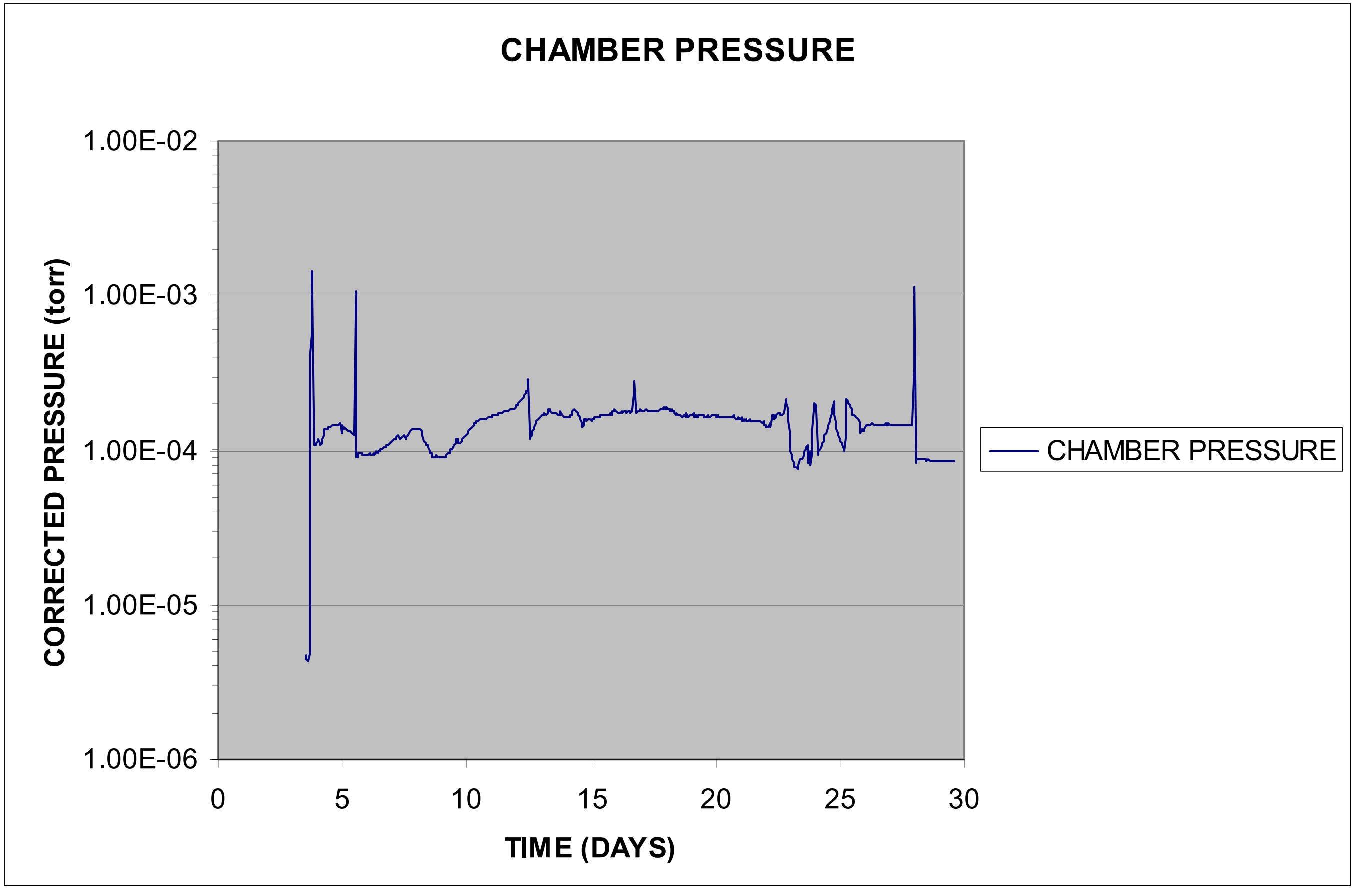
MIRROR SURFACE, CENTER
350
300
250
200
150
100
50
0
TEMP (K)
0
10
20
30
TIME (DAYS)
MSURF.T252, Predicted
Average of LS5SD1 &
LS6SD13 (Mirror Center)

Results

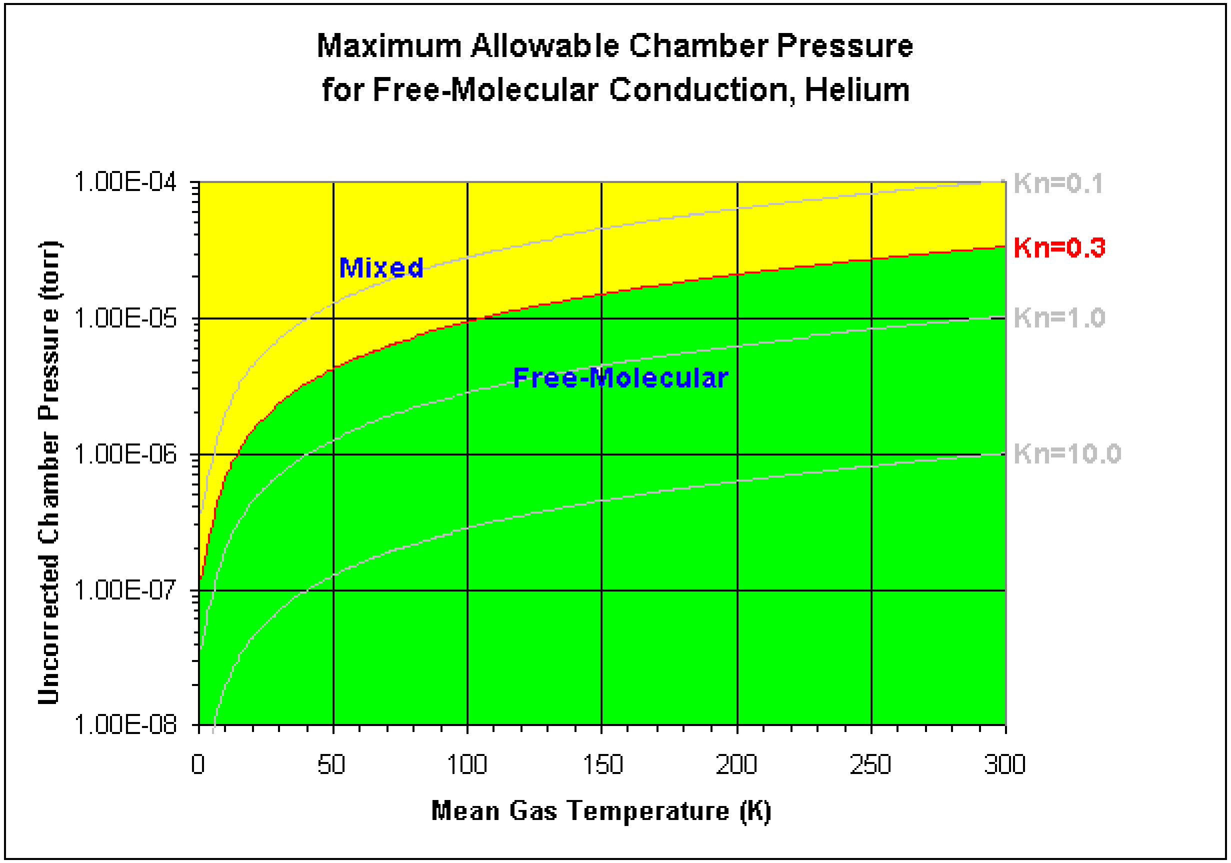


KNUDSEN NUMBER
100
10
1
0.3
0.1
0.01
Kn
Free-Molecular
Mixed
0
5
10
15
20
25
30
TIME (DAYS)
Knudsen Number

Results


CHAMBER PRESSURE
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
CORRECTED PRESSURE (torr)
0
5
10
15
20
25
30
TIME (DAYS)
CHAMBER PRESSURE

Recommendations



References

1. Randall F. Barron, *Cryogenic Heat Transfer*, Taylor & Francis, 1999, pp. 243 – 257.
2. Steven Sutherlin, *The Composite Optics, Inc. (COI) Development Mirror Thermal Analysis Final Report*, MG-01-498, May 30, 2001.